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The Performance of Cold-formed Steel Products in Housing

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THE PERFORMANCE OF COLD-FORMED STEEL PRODUCTS IN HOUSING

By Larry W. Ife, P. Eng.[1]

SUMMARY

The design and testing of cold-formed steel products for a special research house is described. Particular reference is made to the thermal performance of load-bearing studs, vibration tests on steel residential floor joists and full scale load tests on steel roof trusses. Also described is the development of a special nail for fastening subflooring to steel floor joists.

INTRODUCTION

The Steel Company of Canada has been working on the development of steel products for housing for over ten years. During that time, the approach to this development has changed from the first efforts at trying to develop the all-steel, prefabricated, factory-built house (Figure 1) to the present approach of developing individual cold-formed sheet steel components to replace their wood counterparts. Over the last several years, this development has concentrated on such products as steel floor joists, wall studs and roof trusses.

In order to fully develop a new product for housing, it is necessary to get them used in the field under actual conditions of construction and end use. This is difficult to do, however, as builders are reluctant to use products which they are not entirely familiar with or which may not as yet be formally approved by the various regulatory bodies. Also, access to

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monitor the performance of the steel products once the house is occupied can be difficult. So in 1972 when several products were wanted to be included in an actual installation, it was decided to build a research house.

A local builder who was developing a subdivision was approached and an agreement was arranged whereby he would sell one of his lots and be responsible for the construction of the house, using his framing crews and arranging the subtrade work with his subcontractors. The house would be built to one of the plans he was building in the subdivision. An identical wood framed house which could be used as a comparison was also built a short distance away from the research house. By this approach the steel products could be evaluated under actual construction conditions, being erected by normal construction labourers as in a conventional house and in direct comparison with an identical wood house.

After the house was complete and the initial tests had been run, it was rented so that the performance of the steel products could be evaluated under actual living conditions. The house has been completed and occupied for the last three years. During this time several tests have been performed and the performance of the various steel products has been observed. This paper will describe the design and testing of the load-bearing thermal studs, floor joists and roof trusses, which went into this research house, as well as the development of a special fastener for applying plywood subfloors to steel joists.

CONSTRUCTION DETAILS OF RESEARCH HOUSE

The house chosen was a two storey with 1,440 sq. ft. of living area (Figure 2).

A standard poured-in-place concrete basement was used. Pockets were poured at the top of the basement wall for the steel floor joists to rest in (Figure 3). The steel joists were 5-1/2 in. deep cold-formed stiffened channels spaced at 16 in. centres. The subfloor was 1/2 in. thick Douglas Fir plywood fastened to the joists with 1/4 in. diameter self-drilling tapping screws. For the ground and upper floor, the joists were supported at their centre and spanned continuously over the width of the house. Two equal spans of 12 ft. resulted.

Load-bearing steel studs were used in all of the first storey exterior walls. These studs were a standard channel with a 1-1/2 in. wide flange and a 3-5/8 in. deep web. These same studs were used for the front exterior walls of the second floor. The studs were at 16 in. centres for the lower floor and 24 in. centres for the upper floor.

A special load-bearing thermal stud was used for the back exterior walls of the second floor (Figure 4). These thermal studs were the same as the other load-bearing studs except they had five rows of alternatively spaced slots in the web to increase the heat flow path through the stud.

Standard non-load-bearing studs were used for the end wall of the upper storey.

The centre interior wall was load-bearing, supporting the first and second storey floors. Joist sections were used as studs and ran continuously from the basement floor to the second storey joists (Figure 5). All other interior walls were non-load-bearing and were framed using standard studs.

Steel roof trusses fabricated from cold-formed sheet steel hat sections and cold-formed mechanical tubing webs were used (Figure 6). These trusses were spaced at 24 in. centres and spanned the 24 ft. width of the house.

A steel roof cladding system was used (Figure 7). The roof panels were 18 in. wide with a rib in the centre and were 15 ft. long. These panels were fastened to cold-formed sheet steel hat section purlins which ran perpendicular to the trusses at 3 ft. centres.

LOAD-BEARING STUDS

Thermal Design Considerations

The main consideration in the use of exterior steel studs is their thermal characteristics, particularly if the insulation is to be placed between the studs as in wood frame construction. Overall heat loss is not a great concern because the relative small cross section of the web portion of a steel stud does not conduct significant total amounts of heat. What is the main concern is the possibility of condensation and dust marking, particularly dust marking on the surface of interior walls.

condensation - According to ASHRAE (1) relative humidity during the winter months may range from 10% to 60% or even higher. A 40% relative humidity is considered to be representative of a large number of houses. At 40% relative humidity and a temperature of 70°F, condensation will occur if a wall surface falls below 45°F. It is therefore necessary to have a stud which will keep the wall surface at least above this temperature to avoid excess condensation.

dust marking - Dust marking is caused by surface temperature gradients on the wall and by the difference between the temperatures of the wall surface and adjacent air. Dust will accumulate on the cooler areas of the wall faster than on adjacent warm areas. Because of this, the wall surfaces over the studs may be highlighted by vertical streaks of dust accumulation. The exact quantitative requirements for dust marking are difficult to establish; for besides depending on the surface temperatures and the temperatures of the air, dust marking also depends on the duration of the cold weather experienced, the amount of dust in the air, and how often the walls are cleaned and painted.

Thermal Design Requirements

Central Mortgage and Housing Corporation (CMHC) have issued an acceptance bulletin (4), for exterior steel studs which gives maximum allowable surface temperature differentials in order to minimize dust marking and condensation. The "Canadian Code for Residential Construction" (2) gives minimum thermal resistance (R) values for walls to reduce overall heat loss. Table 1 gives these requirements.

TABLE 1

THERMAL DESIGN REQUIREMENTS

Climatic Area (Designated by Mean Annual Degree Days)	Minimum "R" Value for Walls		Maximum Temperature Difference (°F) Between Stud and Centre of Stud Space
	Electrically Heated	Other Than Electrically Heated	
up to 8,000	11.11	8.33	10
8,000 - 11,000	12.50	9.09	8
over 11,000	12.50	10.00	6

where: Mean Annual Degree Days is the average annual product of degree times days below 65°F.

R is the overall coefficient of thermal resistance for walls, $\left(\frac{\text{hr. ft.}^2}{\text{Btu}}\ {}^{\circ}\text{F}\right)$

Design Solution

Results from previous work by Sasaki (8) gave useful guidelines in determining the design of a wall system for the research house. Sasaki found improved thermal performance with steel studs when:

1. Insulation did not completely fill the stud space.
2. Insulation was placed to the cold side of the stud space.
3. Studs had longer heat flow paths due to open web construction or slots cut into the web.

The cross-sectional dimensions of the experimental thermal stud which was chosen for the research house, is shown in Figure 8. Two inches of friction-fit fiberglass insulation was placed to the cold side of the stud space. Figure 9 shows the complete wall section.

Theoretical Calculations

Theoretical calculations were made using the ASHRAE Zone Method (1) to determine the thermal resistance (R) through the stud and the overall coefficient of heat transmission (U) of the wall for wall sections with a wood stud, a solid web steel stud and a slotted web thermal steel stud. The wall sections considered are shown in Figure 9. Table 2 gives the results of these calculations.

TABLE 2

RESULTS FROM ASHRAE ZONE METHOD CALCULATIONS

Stud Type	R Through The Wall Zone At Stud (hr. °F ft.^{2}/Btu)	R For Complete Wall (hr. °F ft.^{2}/Btu)	U For Complete Wall (Btu/hr. ft.^{2} °F)
Solid Web Steel Stud	3.55	7.87	.127
Thermal Steel Stud	7.84	10.20	.098
2 x 4 Wood Stud	8.00	10.20	.098

The slotted thermal stud gives a considerable improvement in thermal performance over the solid steel stud. This is due to the fact that the resistance (R) through the web of the thermal stud is 20 times the resistance through the web of the solid steel stud. The resistance through the thermal stud is only slightly lower than through the wood stud and when combined with the rest of the wall, the thermal stud has the same overall coefficient of heat transmission as the wood stud. This means that the inside wall surface over the thermal stud would be slightly colder than the wood stud but the total heat loss through the wall would be equal.

Thermal Tests

In order to determine the performance of the experimental thermal stud, a field test program was undertaken.

test procedure - The research house was examined for temperature variations on the inside surfaces of the exterior walls using AGA thermal vision equipment. A thermal vision camera registers the infra-red radiation from the wall surface on a detector. This detector converts the radiation into an electrical signal. This signal is amplified and is used to regulate the beam of a cathode ray tube which gives a black and white thermal picture of the surface being examined. The brightness of this picture corresponds to the surface temperature of the wall. Multi-exposure photographs are taken of this thermal picture with a series of coloured filters to produce a picture giving constant temperature zones (isotherms). A calibration chart is then used to translate the different isotherms colours into specific temperatures.

The tests were performed several hours after dark. The outside air temperature at the time of the test was 37°F. All temperature readings were adjusted to be based on a 90°F temperature differential, 70°F inside and -20°F outside. These were the reference temperatures which Sasaki used in his investigations and on which the CMHC requirements are based.

test results - Some typical thermal vision results for surface temperatures and for differences of temperature between the wall of the stud and the middle of the stud are shown in Figure 10 for the thermal stud. The average of all the temperature differences for the thermal studs was $4^{\circ}F$. This is as would be expected when considering the relatively high thermal resistance through the stud that was calculated by the Zone Method. This temperature difference is well within the requirements stated by CMHC and should be such that no objectionable dust marking will occur. There has been no indication of dust marking after three winter seasons of use of the house.

Structural Test of Thermal Stud

In order to determine the influence that cutting slots through the web had on the structural capacity of the thermal stud, a load test was performed on wall panels containing the thermal stud and the solid web stud. These tests were performed at McMaster University in Hamilton, Ontario.

Two panels with thermal studs and one panel with solid web studs were tested. The construction of the panels was representative of the construction in the research house. The walls consisted of two 7 ft.-6 in. long studs spaced at 2 ft. A 4 ft. wide by 7 ft.-6 in. long sheet of 5/16" plywood was attached to one side of the studs and a panel of the same size of 1/2" gypsum wallboard was attached to the other side. Self-drilling tapping screws spaced on 12 inch centres were used for fastening.

The test assembly is shown in Figures 11 and 12. The panel was loaded with both an axial load and a horizontal load. The horizontal load was applied at mid-height of the panel on the compression (plywood) side.

Dial gauges were placed at the top, bottom and mid-height of the wall for deflection measurements.

An initial vertical load of 2000 lbs. was applied to the wall. The horizontal load was then applied in increments to 500 lbs. The vertical load was then increased to 2600 lbs. and the horizontal load to 600 lbs. The horizontal load was then kept constant at 600 lbs. and the vertical load was increased until failure of the panel occurred.

The test results for the panels are shown in Figure 13. The average failure load, 15,000 lbs. $\left(\frac{14,900 + 15,100}{2}\right)$ of the panels with the slotted web stud was not significantly lower (9%) than the failure load, 16,450 lbs. of the panel with the solid studs. This was to be expected as the webs are not called upon to transfer high shear forces. Failure of all the panels occurred by the studs buckling at mid-height. The panels had considerable load carrying capacity beyond their desired design load. This was due in part to the load carrying capabilities of the panel facings.

VIBRATION CHARACTERISTICS OF STEEL FLOOR JOISTS

Introduction

When new steel products are introduced to replace existing products that have been in use for years, the new product's performance is often viewed hypercritically. In the case of steel residential floor joists their deflection performance is sometimes questioned. They are referred to as "springy" or "bouncy".

This had been the case with two previous experimental houses which The Steel Company of Canada, Limited had been involved in with the Housing and Urban Development Association of Canada (6, 7). After the joists had been installed in these two houses, the occupants complained about bouncy floors. As the steel joist sections were stiffer than the equivalent wood sections with equal load and span conditions, it was felt that the problem might be due to vibration rather than deflection characteristics. In one case, (6) vibration tests were performed on the steel floor and an equivalent wood floor and it was found that the steel joists had comparable vibration characteristics to the wood floor. It was concluded that the movement of the steel joist was noticed more because the occupants were aware this was an experimental house and were therefore more observant of their environment.

However, because of these experiences and the fact that vibration design criteria are beginning to appear in codes and standards, (3) it was decided to determine the vibration characteristics of the floors at the research house. The similar wood house was also tested to give a means of comparison as well as a degree of acceptance as there were not firmly established performance criteria by which to judge the results. McMaster University in Hamilton, Ontario was retained to perform the vibration tests on the floors.

Test Floors

The floor joists used in both the steel and wood houses had identical spans and were spaced at 16 in. centres. The steel joists were two span continuous over a centre support, each span being 12 ft. The wood joists were two simple spans of 12 ft. The subflooring was 1/2 in. Douglas Fir plywood. Figure 14 gives the cross-sectional properties of the two joist sections.

In the steel research house carpets with 1/4 in. Poplar underlay were installed in the living and dining room, tile with 1/4 in. underlay in the kitchen, and hardwood flooring in the bedrooms. In the wood house, hardwood floors were used throughout except in the kitchen where tile on 1/4 in. thick Poplar was used. No furniture or loads were present on the test floors.

Test Equipment and Procedure

Vibrations were induced in the floor system by means of dropping a 25 lb. bag from a height of 2 ft. This was chosen because it gave a reasonable vibratory response which could be easily recorded.

The vibration was sensed by triaxial accelerometers attached directly to the floor joists. Amplifiers received the signal and amplified it to a recording machine. The signal was monitored by means of an oscilloscope to ensure that the traces were within the range that could be measured easily.

Velocity transducers were used to record the vibrations for the second floor joists. These units were placed directly over the joists on the finished floors because the joists were not exposed underneath. Six impacts were recorded in each area.

Test Results

Figure 15 is a typical vibration wave showing natural frequency and damping. The natural frequency and the damping as represented by the percentage of the critical damping rate from the tests is given in Table 3. The time (T_0) for the amplitude to reduce to 20% of its initial value and the percentage of the initial amplitude ($A_{1/2}$) which occurs at 1/2 second was also calculated as a comparison with HUD requirements (5).

Figure 16 shows some actual traces from the tests. The natural frequencies of the two systems are within the same range with the steel generally being lower. The wood system had higher damping values. From the vibration traces it can be seen that the damping of the wood system is more eratic than the steel system. The steel system has a fairly uniform rate of decay. The natural frequencies of both systems are such that resonance with human activities within the house would not likely happen.

The characteristics of both systems are very similar and it is felt that there would not be any noticeable difference of performance under normal transient vibrations such as caused by someone walking across the floor.

The HUD requirements stated the transient vibrations induced by human activities should decay to .2 of their initial displacement amplitude within .5 seconds. From the last two columns of the test results it can be seen that both the steel and wood systems are well within this criteria.

Recent guidelines (3) are stating that the important performance characteristic for light residential floors is not vibration response but the performance under a point load. The ability to transfer loads laterally and to minimize relative deflections between joists is the most important performance criteria for acceptable floors. It is not vibrations which lead to complaints of bouncy floors but absolute and relative deflections under point loads. This causes the sensation of bouncing and affects rattling of dishes etc.

TABLE 3

VIBRATION TEST RESULTS

Test Location	Fundamental Frequency (C.P.S.)	Approximate Equivalent Viscous Damping As Percentage Of Critical	t_o	$A_{1/2}$
Steel Joist House				
Living Room	22	4.5	0.32	8.1
Dining Room	22	6.5	0.21	2.3
Kitchen	33	5	0.20	1.8
Bedrooms	26	6	0.32	8.1
Wood Joist House				
Living Room	22	7	0.32	8.1
Dining Room	25	11.5	0.15	0.4
Kitchen	42	9	0.09	0.02
Bedrooms	32	8.5	0.21	2.3

ROOF TRUSSES

Background

Prior to the design of the roof trusses for the research house, the development of a steel roof truss had been going on for over two years. Three previous prototype trusses had been designed and tested. All of the trusses were of the standard residential "W" type of truss configuration.

The first truss was designed using cold-formed "C" sections for the chords and webs. Connections were made by gusset plates and spot welds. Failure under full load test was at 1/2 the desired load and was due to the spot welds giving way. The failure of the welds was due to excess stress at the connections due to secondary moments and poor quality welds.

The second truss tested was fabricated from the same "C" sections as the first truss but the connections were made using self-drilling tapping screws through the gusset plates instead of spot welds. Again, failure of these trusses occurred before the desired ultimate load. Final collapse was initiated by a connection failure which was caused again by the high connection stresses due to the eccentric loading at the connection. The self-drilling tapping screws did perform much better, however, than the spot welds, giving a more reliable and predictable connection.

The third truss tested was fabricated from hat section chord members and mechanical tubing web members. The connections were made by self-drilling tapping screws. These trusses reached their desired ultimate load under full scale test and served as the model for the research house trusses.

Research House Trusses

The research house trusses (Figure 17) were a modification of the third trusses that were tested. The chord members were cold-formed hat sections with no stiffening lips on the flanges. The web members were a continuous piece of mechanical tubing, formed into the configuration of the web system and flattened at the panel points. U-shaped stiffener shoes were placed at each bottom chord panel point. All connections were made with 1/4 in.-14 x 3/4 in. hex washer head self-drilling tapping screws.

A full scale test of the truss was performed. The test set-up is shown in Figure 18. Two trusses spaced 24 inches apart were tested together. 3/4 in. plywood sheets, simulating roof sheathing was fastened to the top chords with self-drilling tapping screws. 1/2 in. gypsum wallboard was fastened to the bottom chords to simulate a finished ceiling condition.

The truss was loaded utilizing concrete blocks. An initial 10 psf load was placed on the bottom chord to simulate the required attic design load. The top chord was then loaded in increments to simulate roof snow loads until failure occurred. Deflection measurements were taken after each load increment.

The test results are given in Figure 19. The trusses performed satisfactorily, exceeding the theoretical ultimate load and exceeding the design load of 40 psf by a factor of 2. The deflection of 0.71 in. at design load of 48 psf was less than the allowable of span/360 = 0.86 in.

During the test, there was no unusual behaviour in any truss member between its respective panel points. The top chord compression member remained flush with the plywood sheathing and there was no evidence of buckling in the top flange. The truss bearing points showed no lateral movement, lift or local buckling.

In each of the web bottom chord panel points, however, the top element of the stiffener shoe lifted away at the tension side of the connection. The total amount of lift was approximately 1/4 inch, but the behaviour of this connection did not appear to adversely effect the performance of the truss other than to increase deflection.

The point of failure was at the peak of the south truss where the two top chords were connected through their bottom flanges to the flattened portion of the continuous web member. Initially there was a space between the chord members but with increasing load the ends beared against each other at the peak until failure finally occurred by the members buckling at this point.

FLOORING NAIL

Introduction

The steel floor joists in the research house were installed easily and quickly. There was considerable time saving over the installation of their wood equivalents. Some of this time saving, however, was lost because it took longer to fasten down the plywood subflooring to the steel joists with self-drilling tapping screws than it did to nail the subfloor to wood joists. Because of this, it was desirable to have a nail which could be used with steel joists. In a previous experimental house a heat treated spiral shank nail had been used with mixed success. It was possible to drive this nail through the steel joists and the nail held fairly well in the steel but it did not clamp or pull the subflooring down firmly to the joists. The result was excessive squeaking. It was necessary, therefore, to use an adhesive with this type of nail to get a satisfactory connection.

A special nail with a screw thread was suggested as a possible fastener for this application. A description of the performance of this nail follows.

Description of Nail

Figures 20 and 21 show the special nail. The nail has a flat, slightly countersunk head, a conical point, spiral screw threads and is heat treated.

The nail functions as follows. The hardened conical pencil point penetrates the wood subfloor and steel floor joist flange and prepares a hole .125 inches in diameter. The screw threads whose outside diameter is 0.145-0.155 inches then cut themselves into the joist flange. The threading is afforded by the difference between the plain point section diameter of the nail and the thread diameter. The thread angle permits the nail to make approximately a 1/4 turn as it is driven through the joist flange. The countersunk head design allows the nail to seat flush with the subfloor. Figure 22 is a photograph of a section of .075 in. thick joist, 1/2 in. plywood and the special nail which has been cut through the centre of the nail. Figure 23 is a blow-up of the nail and joist flange intersection. These figures show how the nail is threading itself into the steel.

The nail was given a phosphate treatment. This treatment etches the surface, increasing its surface friction coefficient and thus improves its holding power.

Testing of Nail

Many small and full scale tests, both in the laboratory and in the field were performed with the nail to determine its suitability in terms of drivability and holding power.

The field tests showed that the nail could be satisfactorily hand driven into .060 in. and .075 in. thick steel joists. It was not possible to hand nail into .090 in. thick joists. There was some difficulty in hand nailing into .075 in. joists which had long clear spans. This was because some of the force in trying to drive in the nail was being dissipated by the joists deflecting. This difficulty was not encountered with the .060 in. joists or the .075 in. joists of short to medium span. In all the tests, the nail held firmly and it was not possible to loosen the plywood.

In order to determine the quantitative holding power of the special nail a series of pull-out tests were performed. These pull-out tests essentially comprised fastening 3 inch square pieces of plywood to joist sections and pulling, by means of special U-shaped jaws, the plywood from the joist in a tensile machine. Figure 24 gives a summary of these pull-out tests. As a means of comparison the calculated pull-out strength of a 2 inch common nail fastening 1/2 inch plywood to a wood (Spruce) joist is also given. The pull-out failure loads of the special nail in a steel joist (329 lbs. and 271 lbs.) are approximately double that of a common nail in a wood joist. Also, the failure mode of the special nail tests was by the plywood pulling over the nail; the nail remained in the steel joist. In order to determine the actual pull-out value of the special nail, some tests were run with a washer placed under the head. This washer precluded failure by plywood pull-over. This gave failure pull-out values of 775 lbs., over five times the pull-out values of a common nail in wood.

CONCLUSIONS

The steel cold-formed products for housing which were used in the research house have performed very satisfactorily.

Specifically:

1. A load-bearing steel stud with slots cut into the web has heat transmission characteristics such that condensation and dust marking is avoided and the overall heat loss of the wall is reduced and is comparable with existing wall systems utilizing wood studs.

2. Steel residential floor joists have vibration and deflection characteristics very similar to their wood equivalents and are such that disturbing vibrations should not exist for normal household activities.

3. A steel roof truss can be fabricated from cold-formed members using self-drilling tapping screws that is structurally adequate and reliable. However, more research needs to be directed at developing a suitable connection procedure that will lend itself to an automated fabrication process.

Also, a special nail with screw threads can be used without adhesive to fasten plywood subflooring to steel residential floor joists.

APPENDIX I - REFERENCES

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2. "Canadian Code for Residential Construction (Residential Standards) 1970", Associate Committee on the National Building Code, National Research Council of Canada, Ottawa, Canada.

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APPENDIX II - NOTATION

The following symbols are used in this paper:

$A_{1/2}$ = percentage of the initial amplitude that exists after 1/2 second.

R = thermal resistance.

t_o = time to reach 20% of initial amplitude.

t = temperature

T = period

U = overall coefficient of heat transmission.

FIGURE 1: EARLY ATTEMPT AT DEVELOPING "ALL STEEL HOUSE"

FIGURE 2: STELCO RESEARCH HOUSE NO. ONE

FIGURE 3: STEEL RESIDENTIAL FLOOR JOISTS

FIGURE 4: STEEL LOAD-BEARING THERMAL STUDS

FIGURE 5: INTERIOR LOAD-BEARING WALL

FIGURE 6: STEEL RESIDENTIAL ROOF TRUSSES

FIGURE 7: STEEL RESIDENTIAL ROOF

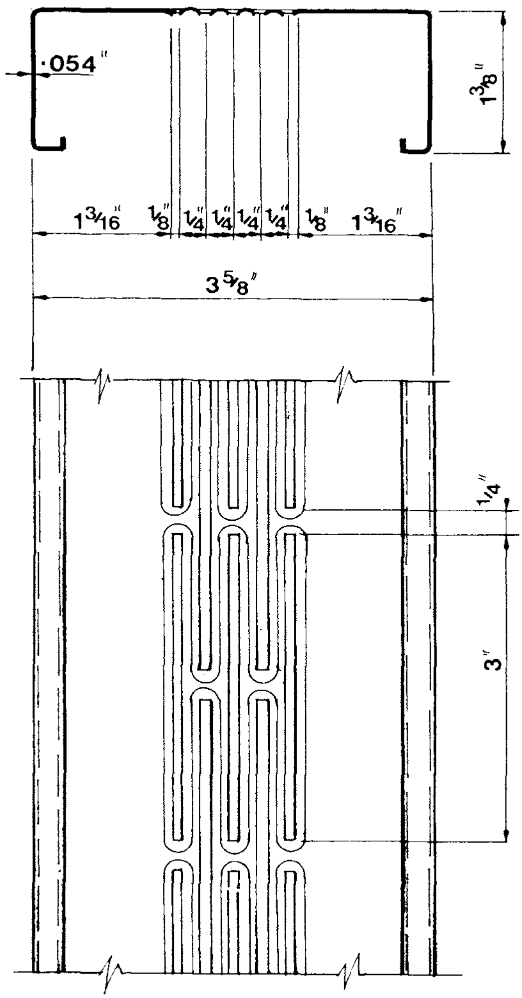


Figure 8
Thermal Load Bearing Stud

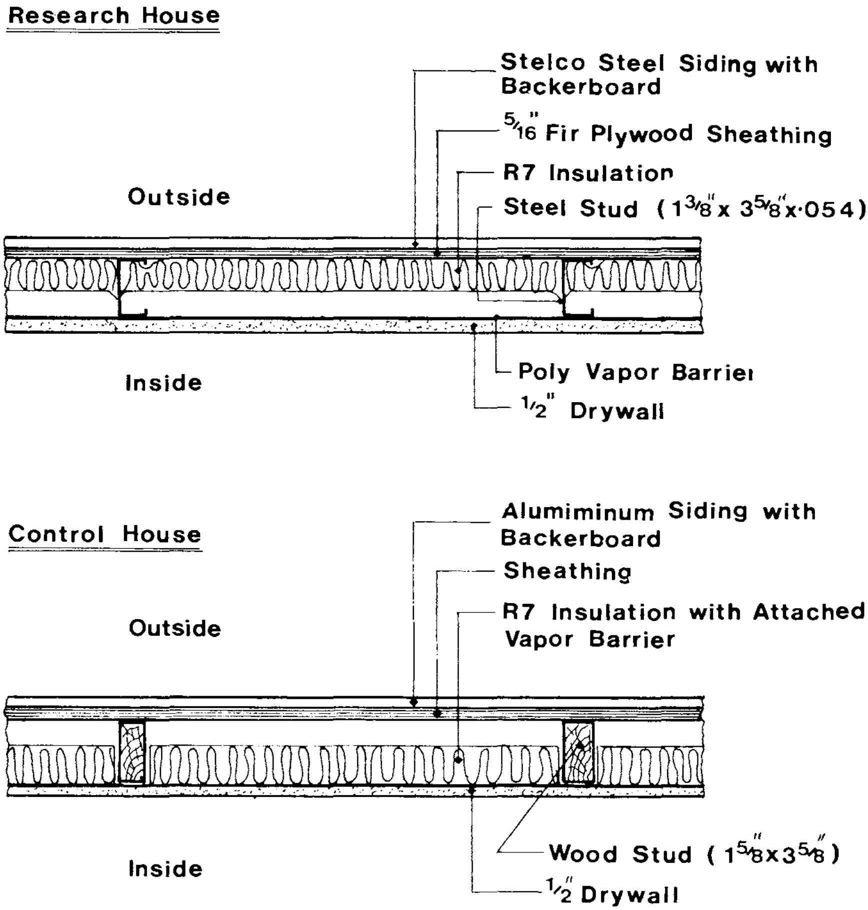


Figure 9
Horizontal Exterior Wall Sections

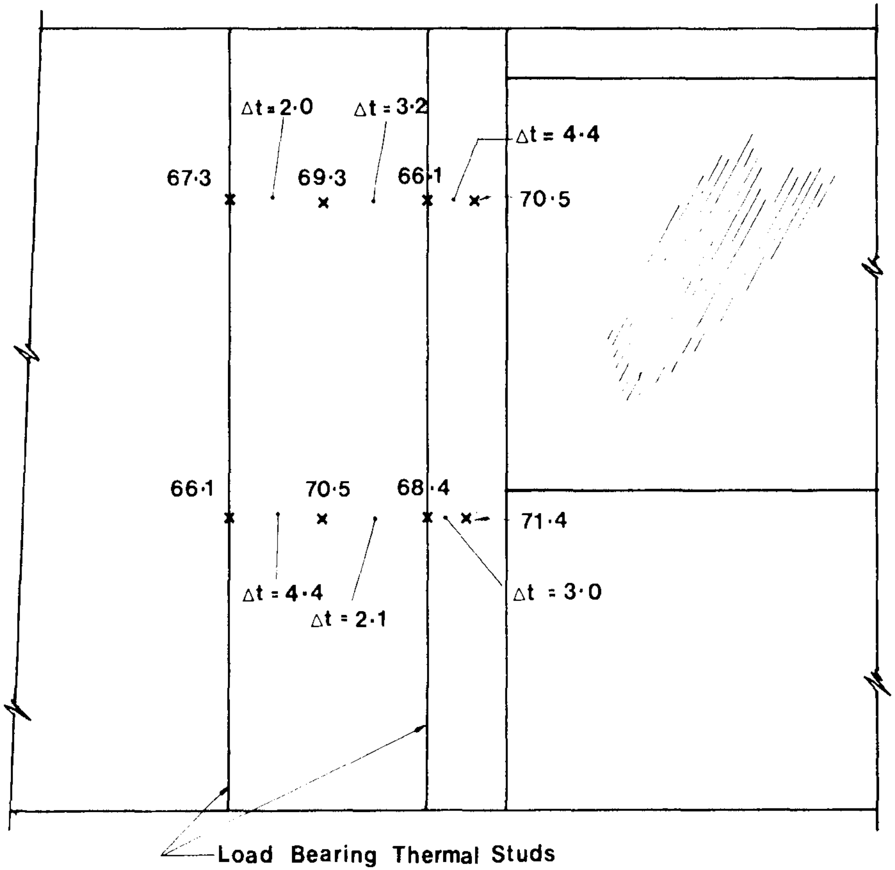


Figure 10
Thermovision Test Results (°f) For Thermal Studs

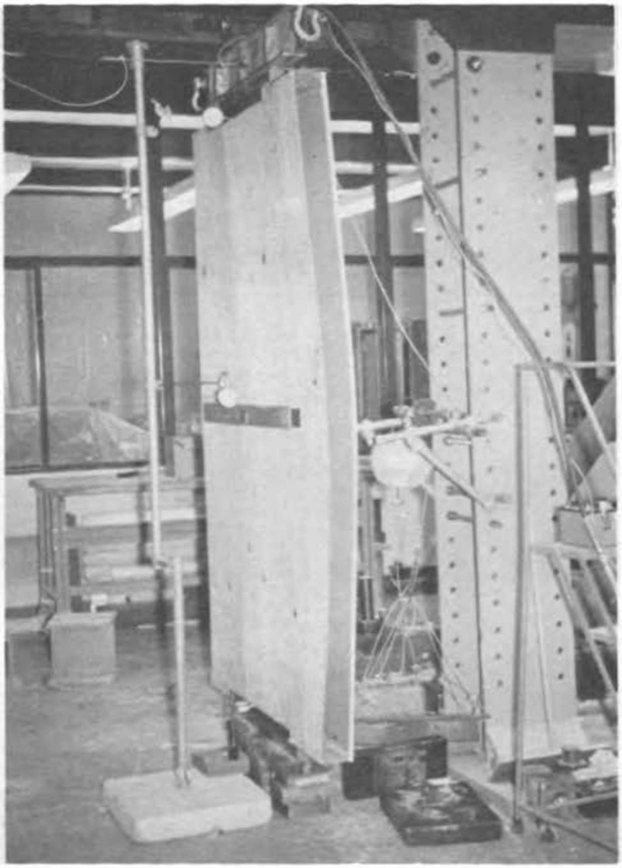


FIGURE 11: STRUCTURAL TEST ASSEMBLY FOR LOAD-BEARING STUD PANELS

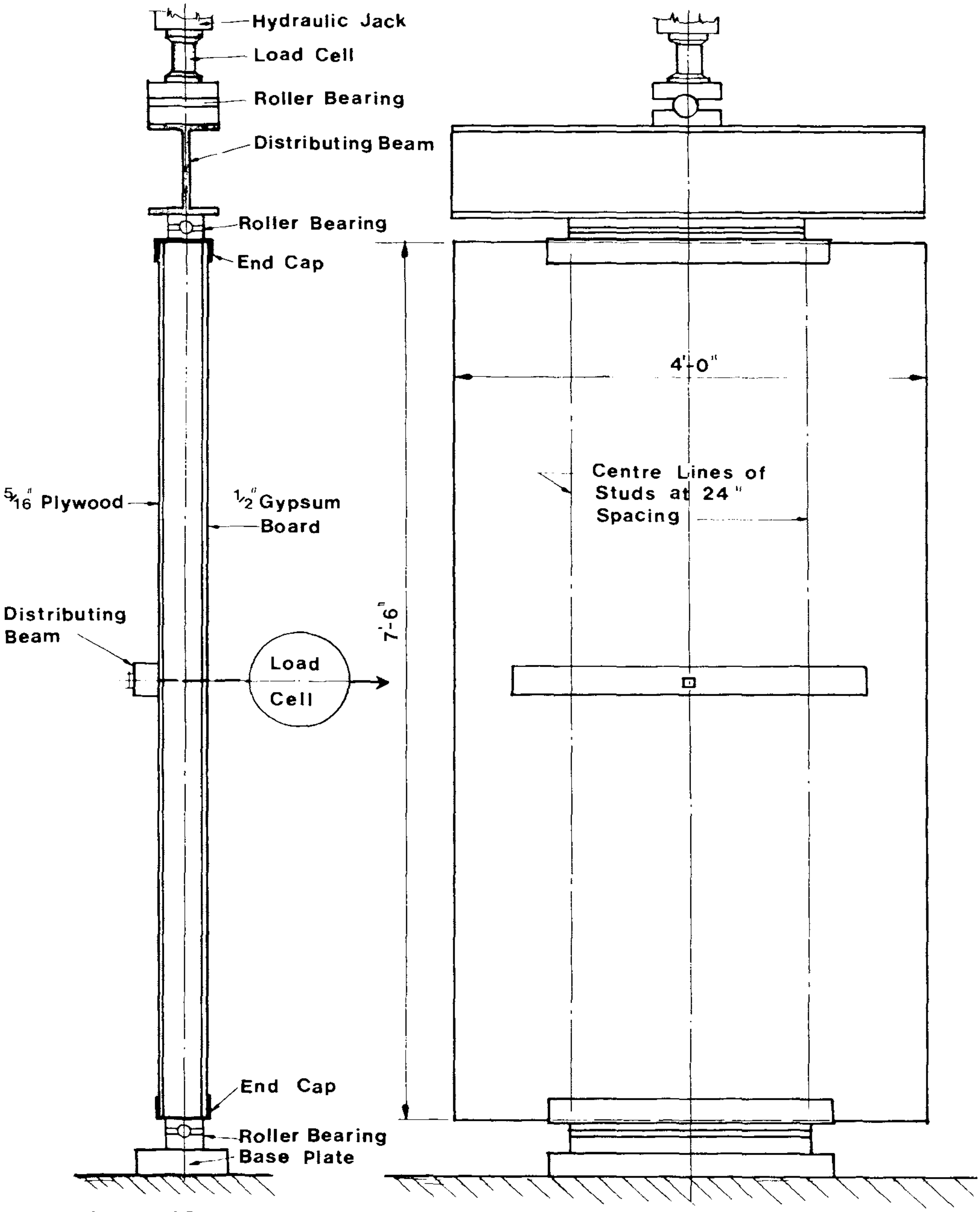


Figure 12
Wall Panel Test Assembly

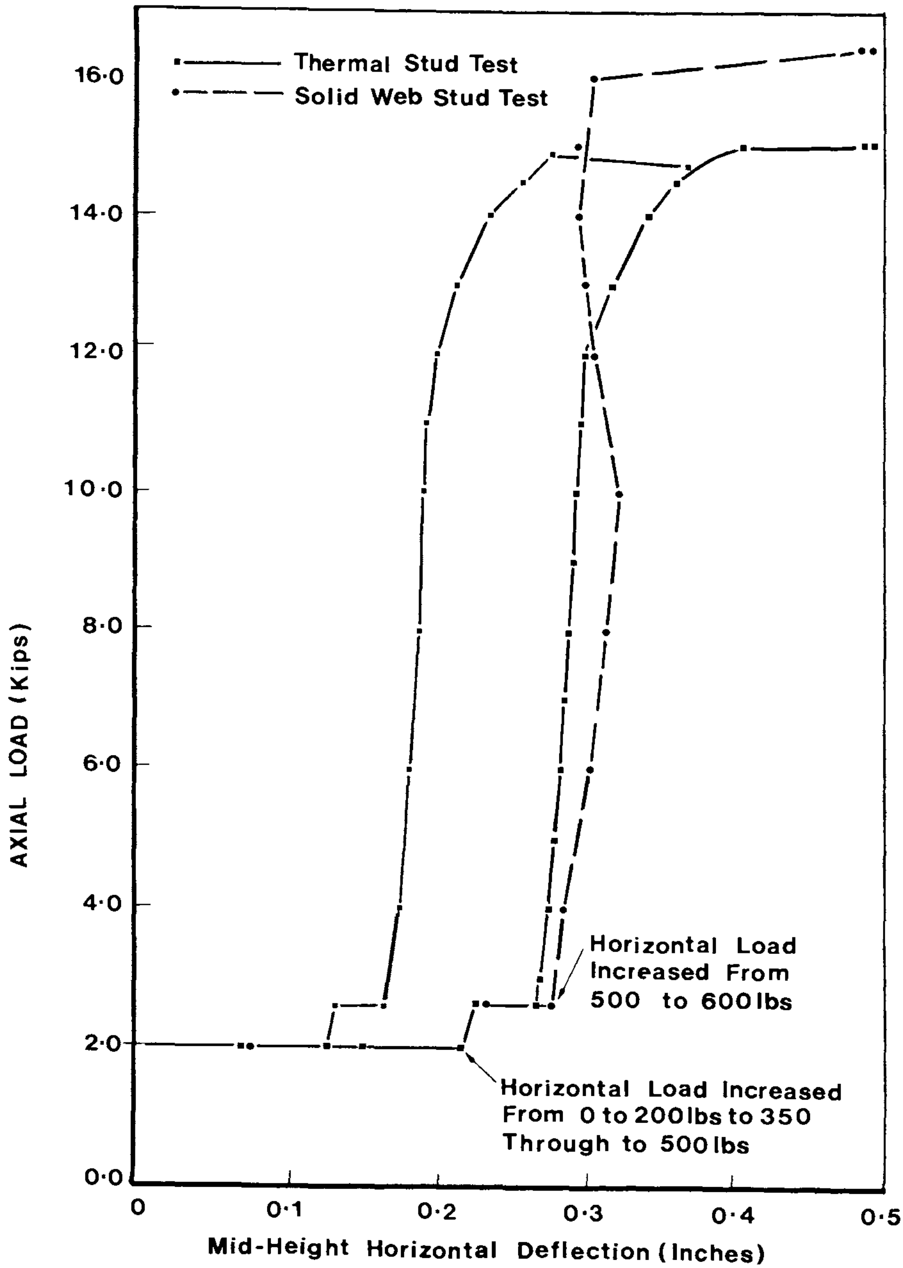
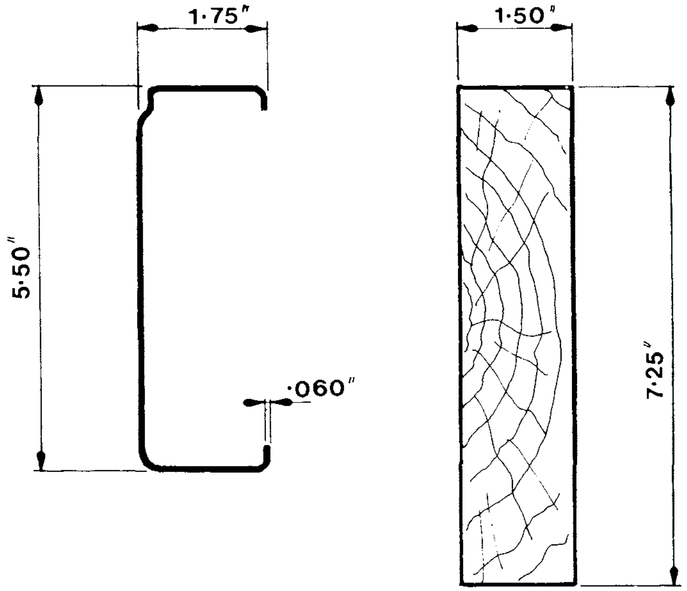


Figure 13

Load - Deflection Data for Wall Panel Test



Residential
Steel Floor Joist

Wood Joist
No 1 Construction
Grade Spruce

	Weight/Ft. lbs	Area in^2	Section Modulus in^3	Moment of Inertia in^4
Steel Joist	1·956	0·561	0·894	2·485
Wood Joist	2·112	10·875	13·140	47·634

Figure 14
Properties of Test Joist

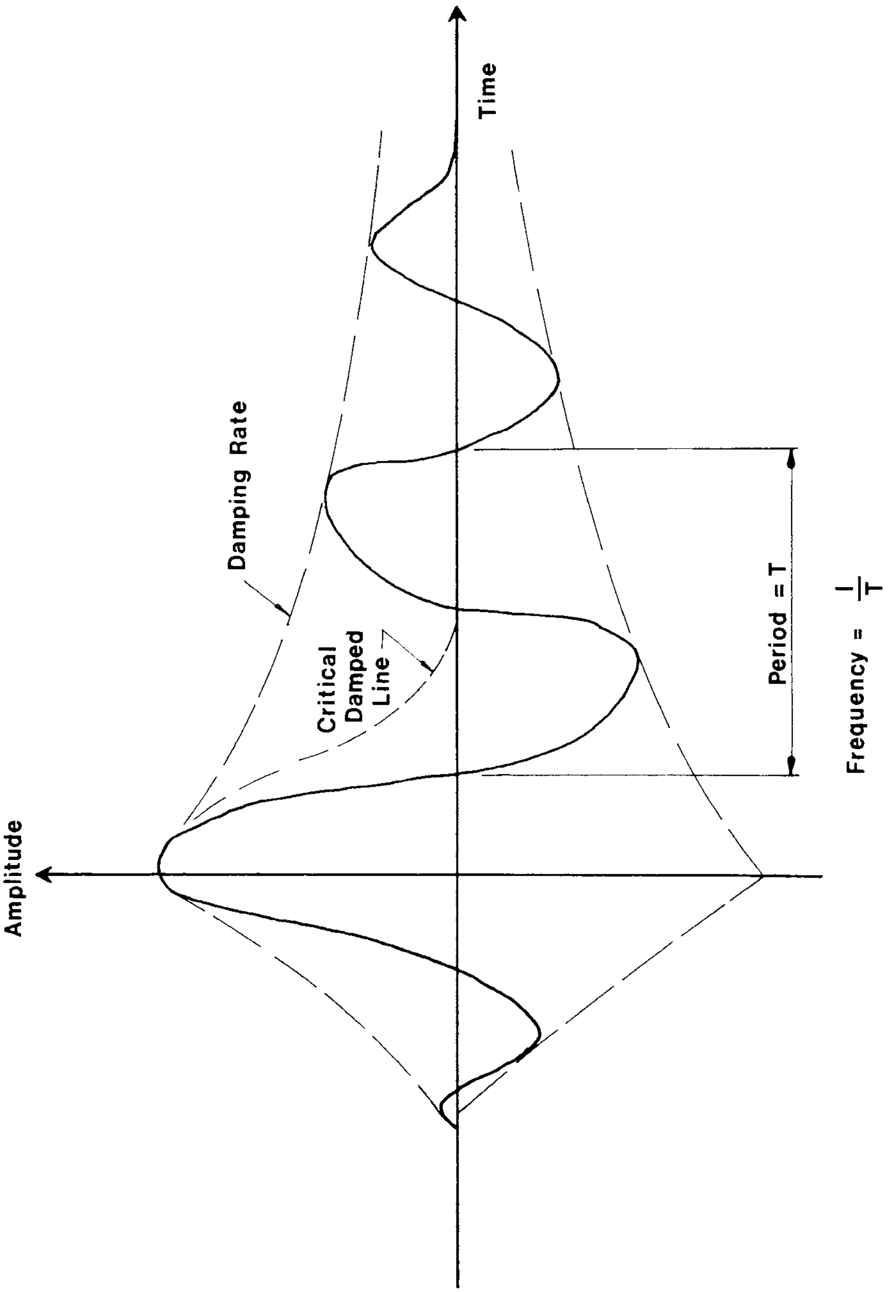


Figure 15
Typical Vibration Wave

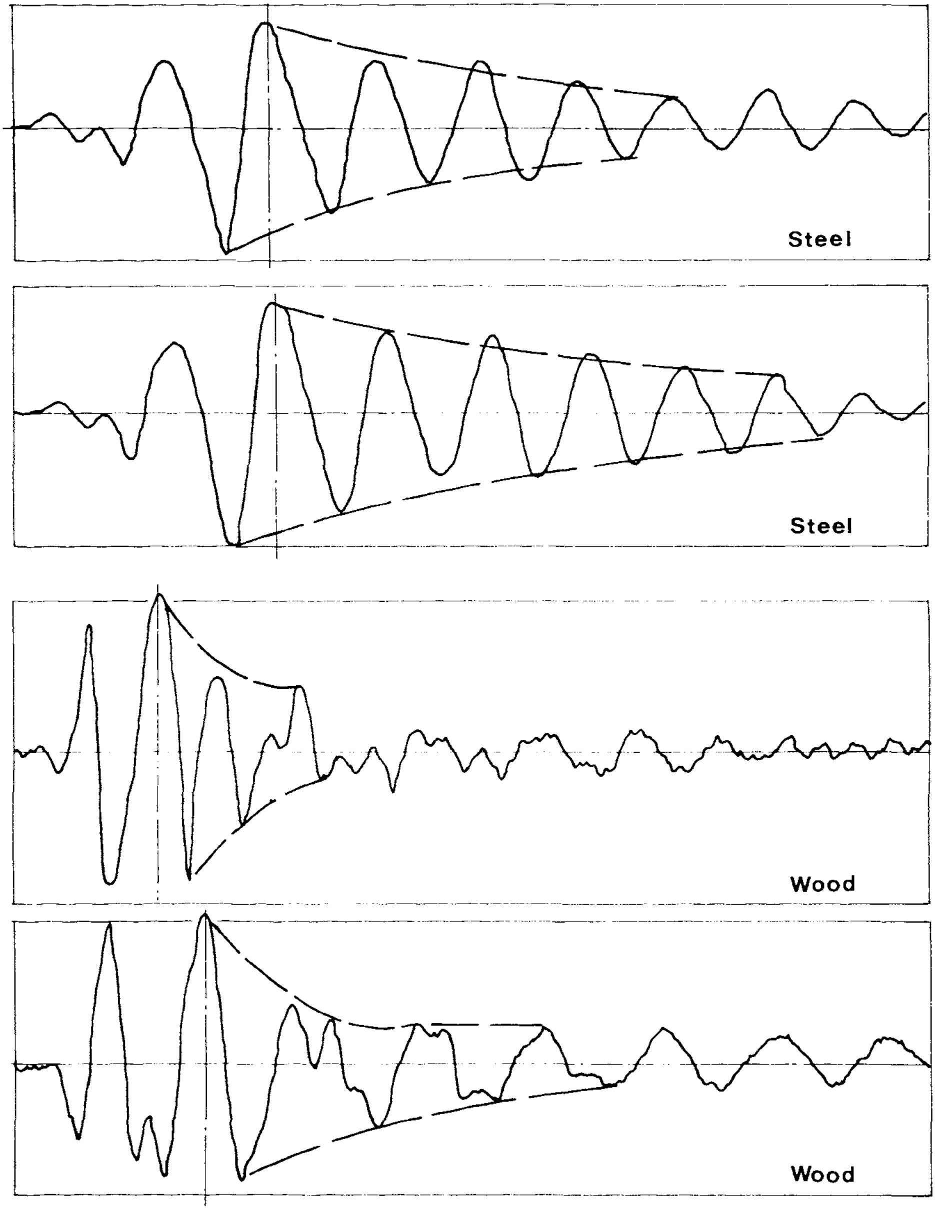


Figure 16
Typical Traces From Vibration Floor Test

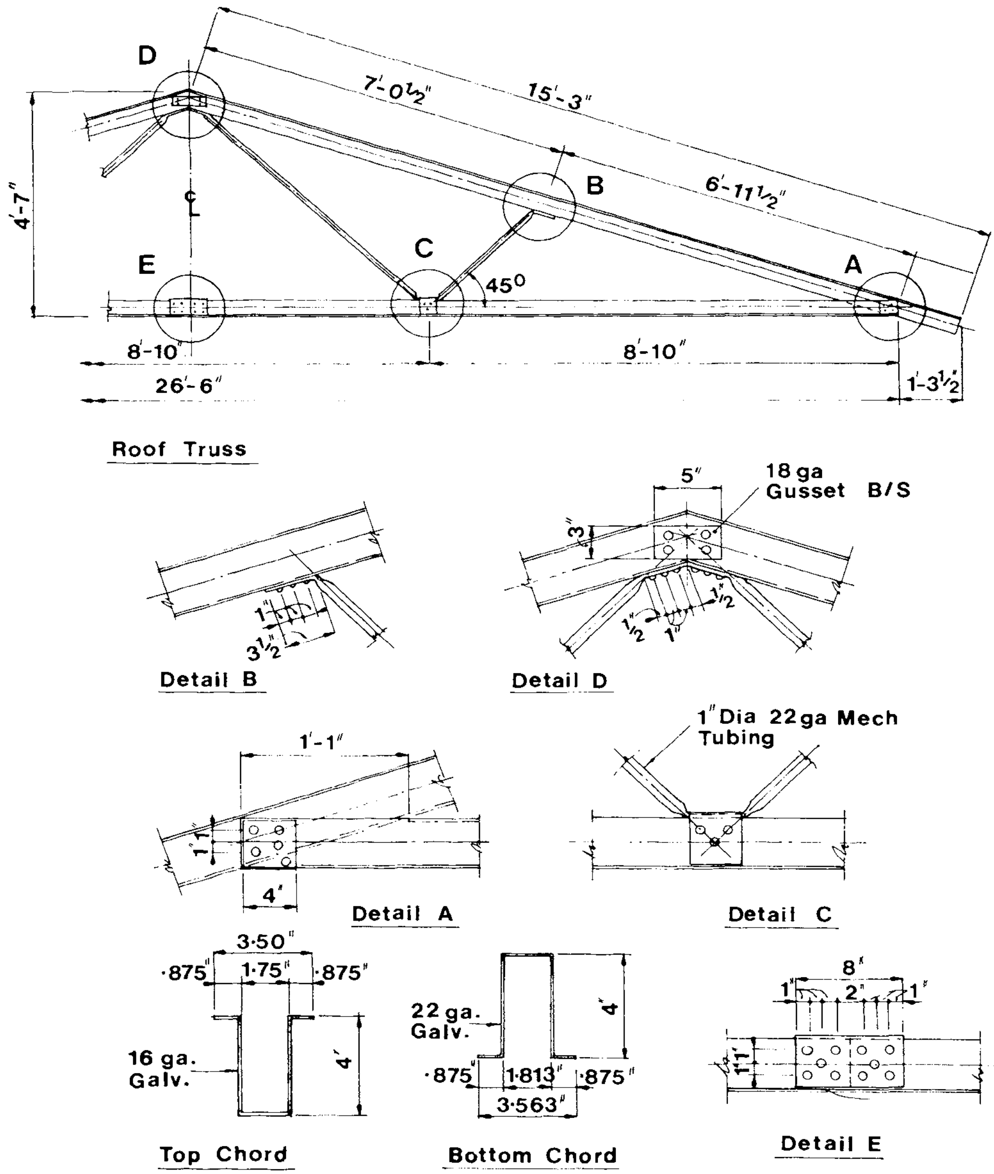


Figure 17
Roof Truss Detail

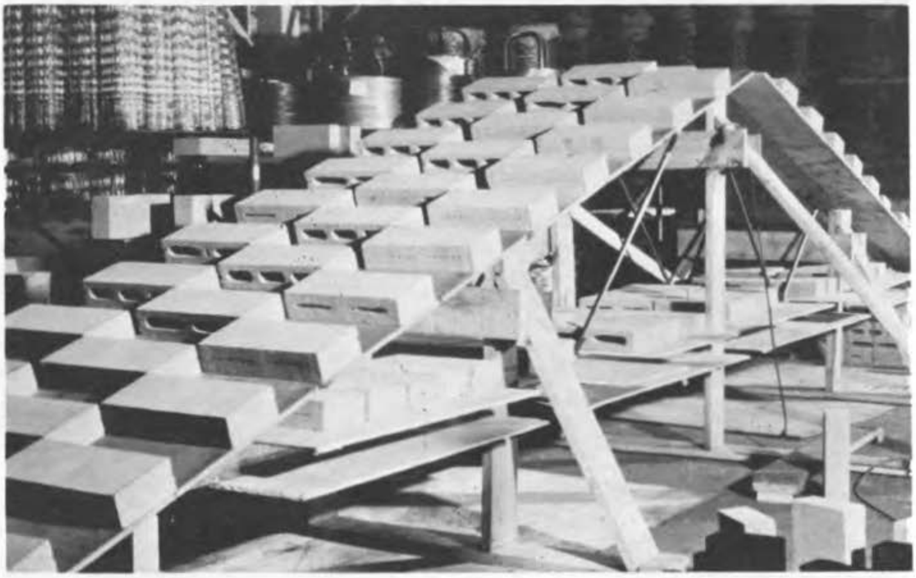


FIGURE 18: STRUCTURAL TEST ASSEMBLY FOR ROOF TRUSSES

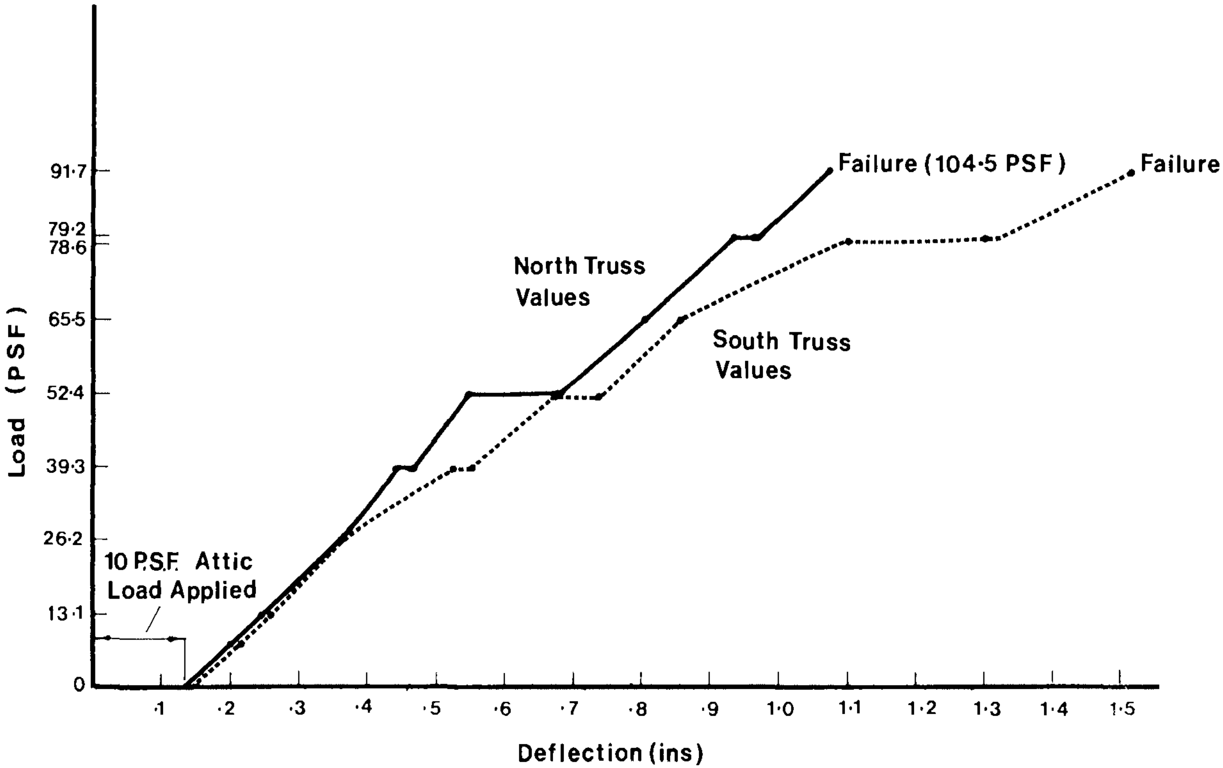
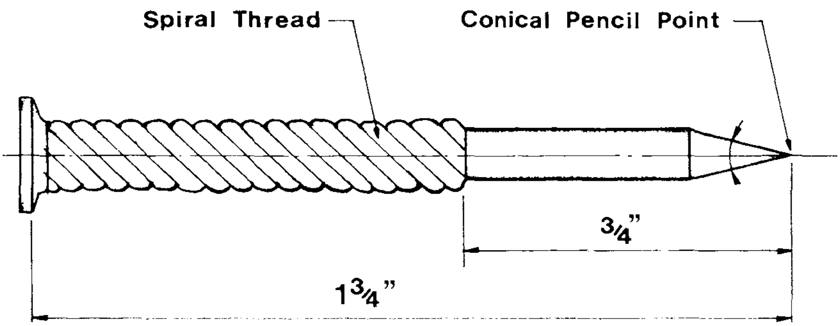


Figure 19
Truss Test Results



Steel Floor Joist Nail

Figure 20

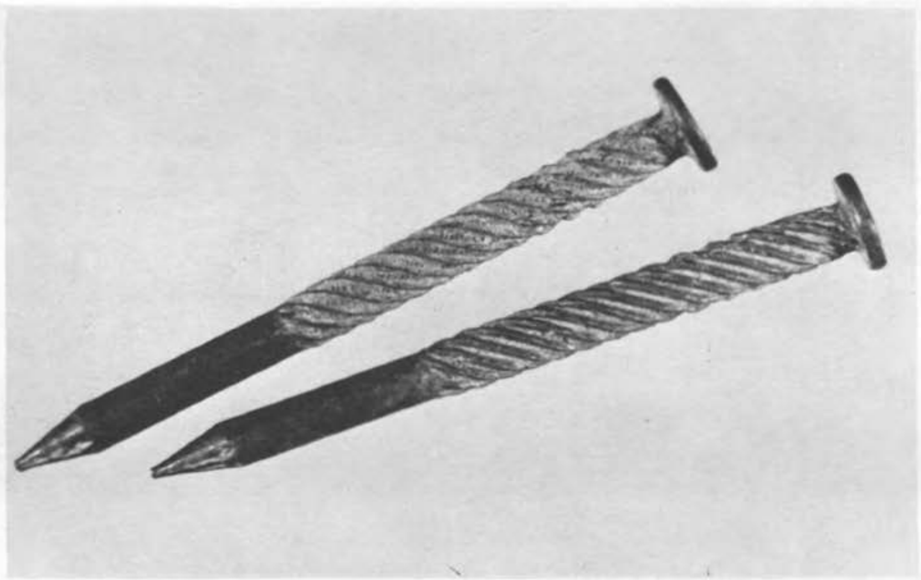


FIGURE 21: NAIL FOR FASTENING PLYWOOD SUBFLOORING TO STEEL JOISTS

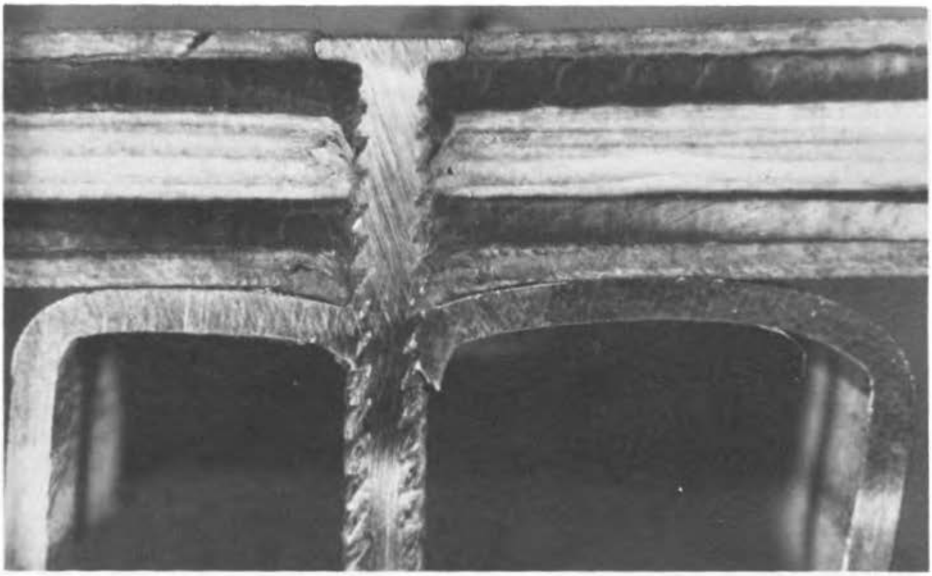


FIGURE 22: SECTION OF NAIL FASTENING 1-1/2" PLYWOOD TO .075" THICK STEEL JOISTS

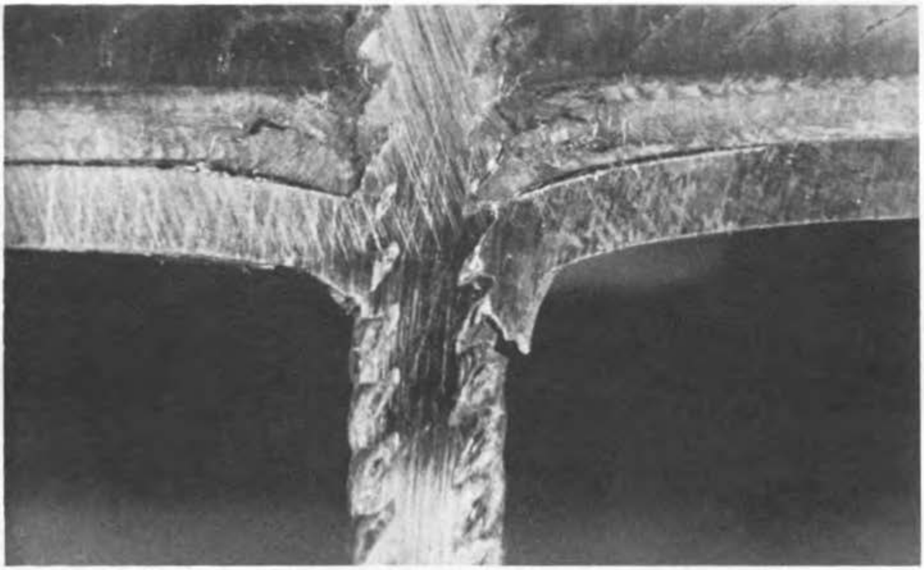


FIGURE 23: BLOW-UP OF SECTION

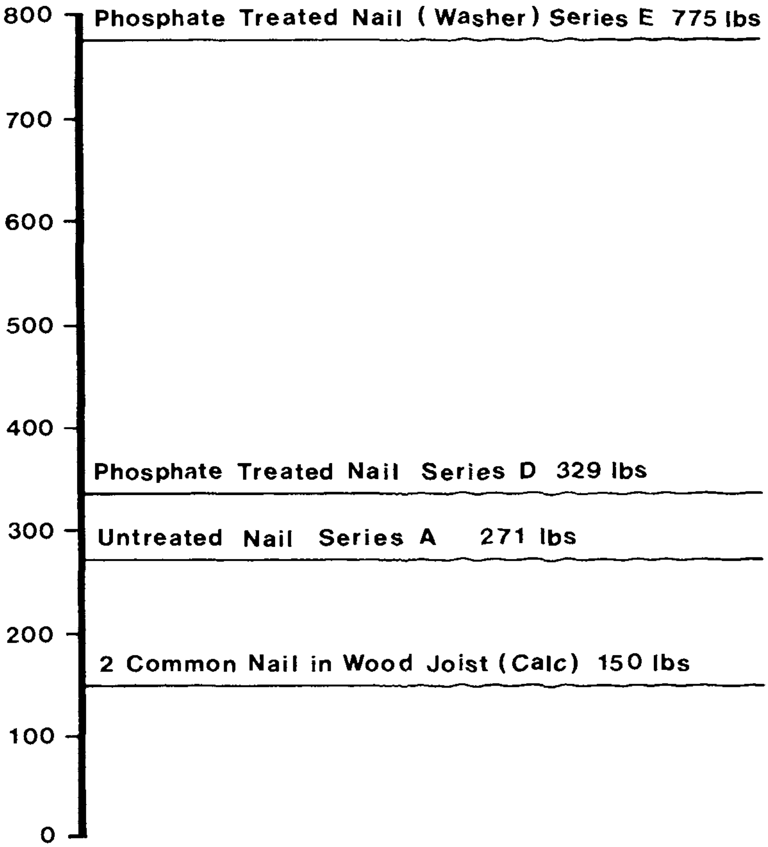


Figure 24
Hand Nailed Pullout Failure Values
For ½" Plywood